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Stratigraphy and Structure in the Triassic Rocks of Central Connecticut

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TRIP B. Stratigraphy and Structure in the Triassic Rocks of Central Connecticut

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Introduction.

The purpose of this trip is to visit selected outcrops of the stratigraphic units which comprise the prism of Triassic rocks in Central Connecticut and to evaluate a new interpretation of the major structural configuration and structural history, which the leader will outline and attempt to defend.

Trip details. The trip will begin at 8:30 A.M., from Portland, on the east bank of the Connecticut River opposite Middletown, under the east end of the highway bridge across the river on U. S. Route 6-A. In general, the line of travel will be westward down the section, beginning near the top. After viewing most of the stratigraphic units, we will proceed northward to the Cedar Mountain structure and outskirts of Hartford, then drive to the Meriden area to see the rest of the stratigraphic units and observe the Hartford fault.

General Geologic Setting.

Considered from the point of view of natural regions, Connecticut, like all of Gaul, is divided into three parts: and Eastern Upland, Central Lowland, and Western Upland (fig. 1). The Eastern and Western Uplands are underlain by pre-Triassic metamorphic and igneous rocks; the Central Lowland, by Triassic rocks. The boundaries between these physiographic entities are sharp and the topographic contrasts are considerable. Though much of the Central Lowland forms a region of low relief and stands at low altitudes, parts of it form ridges, which rise as high as or higher than the surface of the adjacent Uplands areas.

The Connecticut Valley outcrop belt of Triassic rocks extends across Connecticut and Massachusetts from Long Island Sound to northern border of Massachusetts. This belt is 95 mi. long and 15-18 mi. wide.

Stratigraphy

The Triassic rocks consist of a thick prism of non-marine sedimentary strata which contain three intercalated persistent basaltic lava flows and sundry generally tabular intrusive masses, whose composition closely resembles that of the lava flows. Owing to the monotonous yet laterally variable characteristics of the exposed sedimentary rocks and their lack of topographic expression and scarcity of outcrops, stratigraphic subdivision is possible only by utilizing the lava flows as key beds. The basaltic lava flows form prominent ridges and can be distinguished from each other with substantial confidence on the basis of thickness. The geologic "facts of life" are such that one most commonly has to deal with linear ridges of basalt formed by erosion of the tilted edges of the lava flows, and strike valleys between them which are largely covered intervals.

The stratigraphic units thus defined by the lava flows are therefore contemporaneous throughout (= time-stratigraphic units). They are referred to everywhere by the same name, even though their petrographic attributes may change completely from one locality to another, of even if these attributes are totally unknown, as is commonly the case. A broad, three-fold subdivision is immediately apparent, consisting of: 1) all the deposits below the lowest lava flow, 2) all the strata above the highest lava flow, and 3) the lava flows and sedimentary beds intercalated between them. This order was first acknowledged by James Gates Percival (1842), a man of consummate genius, who made the first geologic map of Connecticut with such skill and accuracy that only after issuance of the new U. S. Geological Survey $7\frac{1}{2}$-minute quadrangle maps beginning in 1946 have any important revisions been demonstrated in Percival's mapping.

The basis of the present nomenclature was laid by Krynine (1950), who proposed New Haven arkose for all the strata below the lowest lava flow, Portland formation for all the rocks above the upper lava flow, and Meriden formation for the lava flows and interbedded sedimentary rocks. Although Krynine's nomenclature has been widely accepted, it is not without objections. The name "New Haven" has been long preoccupied by a limestone of Pennsylvanian age in Illinois and "Portland" is a long-standing name for one of the standard stages in the Upper Jurassic. Both of Krynine's terms can be defended on the grounds of local utility, but unequivocal acceptance of them perpetuates practices in stratigraphic nomenclature which generate confusion. The term "Meriden," on the other hand, though very useful, seems destined to fall by the wayside for want of sufficient hierarchichal terms above the rank of "formation." The lava flows of Krynine's Meriden "formation" were earlier named by B. K. Emerson (1891; 1898): Talcott (1898), for the lower; Holyoke (1891), for the middle; and Hampden (1898), for the upper. Lehmann (Ms. on Middletown quadrangle) proposes Shuttle Meadow formation for Krynine's Lower Sedimentary member of the Meriden formation, and East Berlin formation for Krynine's Upper Sedimentary member, and advocates that these and the lava flows be given the rank of "formation." Meriden as a "group" name for these five formations runs afoul of the term Newark "group," which has been applied for the entire prism of Triassic rocks.

Though each unit of the sedimentary rocks displays distinctive characteristics of composition, texture, and primary structures in its type exposures, considerations of the framework of deposition during the Triassic, present conditions of outcrop, and close study in areas away from the type localities indicate that these differences are more the products of natural bias than of fundamental reality. Many rock types occur at different stratigraphic levels away from the eastern border of the Triassic outcrop belt, but nearly all of them pass laterally into coarse conglomerate as the eastern border is approached at nearly any stratigraphic level. The parameter of distance from the eastern border, therefore, is an important control on the aspect of the rocks; owing to the rapidity of the lateral facies changes, this parameter cannot be overlooked.

The following table shows the names of the stratigraphic units, their thickness in Central Connecticut, and composition.

Name	Thickness (feet)	Description
Portland formation	An unknown number of thousands	Medium- to coarse-grained red arkose and pebbly arkose. Bedding regular. Boulder conglomerate near eastern border.
Hampden basalt	75-125	Vesicular and amygdoloidal basalt. Locally contains pillows, according to Lehmann (ms.). Several flows present.
East Berlin formation	600-900	Fine-grained sandstones, siltstones, and silty carbonate rocks; local black shales. Even bedding and much lamination. Boulder conglomerate near eastern border.
Holyoke basalt	600	At least two separate flows of basalt; locally as coarse as dolerite.
Shuttle Meadow formation	350	Evenly bedded, mostly red siltstone and sandstone, with thin limestone in areas away from border fault; coarse red sandstone and conglomerate near border fault.
Talcott basalt	100	A complex of several basalt flows and interbedded sediments; pillows are a noteworthy feature.
New Haven arkose	An unknown number of thousands	Pebbly red arkose and associated red siltstone; bedding generally is not regular.

Table 1. Triassic formations in central Connecticut. (Descriptions largely after Krynine, 1950, p. 32).

STRUCTURE

Introduction.

The outcrops of the lava flows (referred to as "trap sheets" in the earlier literature), which form the key beds for interpreting the geologic structure, were accurately shown on Percival's (1842) map, but he was not able to synthesize the structure, even though he clearly indicated his belief that most of the trap ridges were outcrops of the same three sheets (now known to be lava flows), which were found together everywhere in the same stratigraphic order and bore the same relationships to beds below and above. Percival spoke of the offsets of the ridges in terms of "advancing-" or "receding" order, depending on whether the south end of the more northern member of two adjacent ridges was located farther west or farther east, respectively, than the north end of the southern member of the pair.

Little interest was shown in the structure of the Triassic rocks during the decades when the "trap sheets" were regarded as being intrusive, for no basis for structural interpretation could be found in the poorly exposed sedimentary rocks. In 1882 W. M. Davis became convinced that certain of the "trap sheets" are ancient lava flows and could be considered as key beds for mapping, as if they were distinctive sandstones, for example. In a series of brilliant papers that extended over a period of nearly 20 years, Davis unraveled the structure of the Connecticut Triassic and demonstrated that tilting, warping, and faulting of an originally horizontal mass of strata had occurred and that the present topographic distribution of most of the basalt outcrop ridges could be explained by fault offsets of only three intercalated lava flows. Davis also proved the eastern contact of the Triassic rocks is a border fault.

Davis, however, supposed that only one episode of faulting had taken place, i.e., that which produced what will be here called the Lowland fault system and at the same time established the border fault. He held that these faults occurred after the depositional trough (which he considered to have formed by downwarping) had been filled and after gentle folding of the originally horizontal strata had occurred. Davis thought that the Triassic beds once extended further east than their present eastern termination against the border fault. One of his arguments for the existence of the border fault was the abrupt truncation of the warped structures against the metamorphic terrane at the eastern border. Davis presumed that these structures were simply cut in two by the border fault and that their eastern parts were destroyed by erosion after uplift on the raised block east of the border fault. Though the remarkable hypothesis of origin of the faults in the Triassic strata as a result of straightening out of curved slabs of the underlying metamorphic rocks by lateral compression which was championed by Davis (1886; 1888; 1898) has not attracted many adherents, the existence of the Lowland fault system and the eastern border fault have become permanent fixtures in the interpretation of the Triassic rocks.

Burrell (1915) believed the trough formed initially by downwarping, but was the first to show that significant movement took place on the eastern border fault during Triassic deposition. The importance of syn-sedimentation faulting was further demonstrated by W. L. Russell (1922) and C. R. Longwell (1922; 1937). Russell proved that the Triassic strata never extended further east than the border fault and that repeated uplift of the Eastern Uplands block rejuvenated topographic relief to supply coarse sediment throughout the entire depositional history. (For further details on this subject, Trip E, on Sunday, is recommended.) Russell suggested that the warped structures, instead of being cut off randomly by the border fault, as Davis believed, were in fact related to drag on the fault and originated as a consequence of fault displacement. Russell was not specific about the details, but I get the impression from reading his paper that he thought the eastern border fault, which now dips westward, was always a "normal" fault and that the post-depositional faulting was not much different from the syn-sedimentation faulting, but that somehow in between sedimentation stopped and the warped structures formed during post-depositional movement. Longwell (1922; 1937) also elaborated the case for faulting during Triassic deposition on the basis of the coarse sediment found along the border fault, which he was able to compare with alluvial fan deposits of Cenozoic age in southern Nevada. In these papers Longwell argued that the eastern border fault is a "normal" fault and presumably always was, in spite of his own remark that the border fault would dip southeast (i.e., be a reversed fault) if the strata were rotated back to their initially horizontal or slightly west-dipping position from their present eastward dip (1922, p. 231). Bain (1932) insisted that the border fault in Massachusetts is a reversed fault, but met with firm opposition from all quarters and has found few supporters of his interpretation.

Girard Wheeler (1939) followed up W. L. Russell's (1922) suggestion that a genetic connection exists between warped structures in the Triassic rocks of Connecticut (and New Jersey) and movements on the border fault. Wheeler proposed a theory of origin which relates the warped structures to changes in strike and dip of the border fault. According to Wheeler, narrow "anticlines" with axes perpendicular to the border fault, occur opposite "bumps" on the fault surface, whereas "half-synclines" ("half-basins" of this paper) occur opposite re-entrants in the fault surface. Wheeler examined the problem of the dip of the border fault in Connecticut in great detail and concluded that it is a "normal" fault and everywhere dips westward, and that it also had this dip when the warped structures formed. In my opinion, Wheeler's hypothesis of the origin of the warped structures is accurate as far as it goes, but does not sufficiently consider the significance of the syn-sedimentation faulting emphasized by Russell and Longwell, nor does it explain why sedimentation ever stopped if the Lowland block moved downward during deposition and also afterward.

It seems to me that the following interpretations are well enough established to serve as guideposts for any structural history and that none of the previous syntheses of the structural history adequately explains all of them:

1) Syn-sedimentation faulting took place on a large scale. During this episode of movement, the Lowland block moved relatively downward a total distance of some tens of thousands of feet, but <u>no warped structures formed</u> (as proved by the present parallelism of outcrops of the lava flows and absence of angular discordance between exposed sedimentary strata).
2) Sedimentation stopped. (This point might be disputed on the grounds that any further sediments in the trough were eventually eroded away, as the top is not known even now. This I readily concede, but at least on the present level of exposure, the record is of deposition, and then of an end of deposition.)
3) Further downward movement of some thousands of feet of the Lowland block along a west-dipping (= "normal") eastern border fault caused the warped structures to form.
4) At some time the strata acquired their eastward dip.
5) The warped structures were offset by movements on the Lowland fault system. Movement on the Lowland fault system post-dates both warped structures and eastward dip, for essentially vertical displacement caused the lateral offset of warped and tilted beds.
6) All deformation involves the "basement" primarily, and the Triassic strata have behaved relatively passively atop their foundation. It seems probable, therefore, that the depth of deformation extends through the entire thickness of the Earth's "crust."

Before elaborating my own ideas on the structural chronology, I will describe the structural arrangement in more detail.

<u>Description</u>.

The Triassic rocks of Connecticut are customarily described as comprising an eastward-dipping monocline which is terminated on the east by a border fault. Although this remark is generally true, it tends to obscure the fact that the Triassic strata have been bent into a series of "folds," whose presence is shown by curvature of the ridges underlain by the basaltic lava flows as well as by the strike and dip of the sedimentary rocks.

These warped structures are most clearly expressed in the topography of the Branford quadrangle, south of the area of this excursion. Altogether, five "half basins" and four intervening narrow "anticlines" can be identified in the Connecticut Valley outcrop belt. The following list names the structures, beginning with those in the south and proceeding northward; the names in parentheses are the authors of the terms: Saltonstall "half basin" (Davis), North Branford "anticline" (Sanders), Totoket "half basin" (Davis), unnamed "anticline," much faulted, Middletown "half basin" (Davis), Cedar Mountain "anticline" (Davis), Springfield "half basin" (Davis), Amherst "anticline" (Davis), and Deerfield "half basin" (Davis). See Fig. 2.

The warped "half basin" structures vary in size from Saltonstall, the smallest, which is 5 miles long and 1 3/4 miles wide, to Springfield, the largest, which is 52 miles long and 10 miles wide. Structural relief on these warped features is on the order of thousands of feet. The basement is clearly involved in the Amherst "anticline" and doubtless also participates in all the others, though "basement" rocks are not elswhere exposed at the present topographic surface.

The warped structures have been displaced by faults of the northeast-trending Lowland fault system, which are for the most part "normal" faults with steep northwestward dip. Essentially vertical displacement on these faults has caused offset of the previously tilted and warped strata.

My own unpublished studies of the Saltonstall and Totoket "half basins" and the North Branford "anticline" in the Branford quadrangle, under the auspices of the Connecticut Geological and Natural History Survey, indicate that the warped structures end abruptly on the west along a fault (Foxon fault) and that beds west of the fault are not warped. From this observation, I have concluded that an essential prerequisite for the warped structures is the existence of a block bounded on both sides by a fault, thus allowing the strata on the block to deform independently of those on adjoining blocks. A possible explanation of the different size of the warped structures may be found in the different widths of the faulted blocks on which the warped structures occur. Such faults represent an earlier period of movement on parts of the Lowland system, for they are contemporaneous with warping and earlier than the main Lowland system, along which the warped structures have been displaced.

Considering Davis' knowledge of the warped structures, it is surprising to me that he placed so much emphasis on the Lamentation block as a major structural element and considered it to be displaced from the Hanging Hills block. Davis' view of the Lamentation block is presented in fig. 3, and on the geologic map, fig. 4. The Lamentation block has been doing duty in the literature for many years and is also the source of the oft-quoted figure of 5000-6000 feet for the thickness of the New Haven arkose (1898, p. 101; see also Longwell, 1928, p. 262). Davis arrived at this figure by measuring the horizontal distance obliquely along the block from the base of the Talcott lava flow to the western border of the Triassic outcrop and by trigonometric calculation of the thickness from an assumed average dip of 15° and projected distance perpendicular to the strike, on the assumption that no other faults are present. The existence of the faults presumed to bound the Lamentation block as extended southwestward from Lamentation Mountain by Davis into the Mt. Carmel quadrangle is stoutly denied by C. E. Fritts, of the U. S. Geological Survey, (personal communication) who is studying this quadrangle as part of the co-operative mapping program in Connecticut. I also question the validity of the Lamentation block hypothesis on grounds of the geometry of the warped structures. I think that the Lamentation and Chauncey Peak blocks are merely slightly displaced parts of the Middletown "half basin" and that they have nothing directly to do with the Hanging Hills block, which I consider to be a part of the much larger Springfield "half basin," which lies next north of the Middletown structure. Using the "half basins" as the controlling structural pattern, I have suggested that the major fault of the Lowland system is the Hartford fault and that along it essentially vertical movement has caused displacement of the Springfield "half basin" from the outskirts of Hartford north of the Cedar Mountain anticline to the Hanging Hills in Meriden (fig. 5). Though I feel the geometry of the warped structures demands this interpretation, I have not as yet solved all the problems concerned with it. For example, as my colleague, John Rodgers, points out, if the axial plane of the Cedar Mountain anticline is essentially vertical (and I might add, if it extends across the Hartford fault), then only strike-slip movement can explain any offset of it. As I have other reasons for doubting large-scale strike-slip movement, I must turn elsewhere for the explanation of the supposed offset. Perhaps the solution lies in the change of size from the Middletown to the Springfield "half basins." The Middletown structure is 15 miles long and 6 miles wide, whereas the Springfield structure measures 52 by 10 miles. According to my present view of the origin of these warped structures, such a change may be brought about by a change in the width of the fault block concerned. The Cedar Mountain "anticline," which intervenes between these two "half basins," may be only as long as the width of the block which contains the Middletown "half basin." The larger Springfield block may not contain the Cedar Mountain "anticline." If this be true, then essentially vertical movement on a north-northeast-trending "normal" fault could cause southwestward displacement of the wider western part of the Springfield "half basin," where the beds strike northwest and dip northeast, but need not offset the Cedar Mountain "anticline," which would never have extended farther northwest than this fault.

Interpretation of structural history.

To recapitulate the results of previous students of the structure of the Triassic of Connecticut: Percival (1842) recognized the curved and offset basalt ridges; W. M. Davis proved that the basalt units could be used for key beds and demonstrated that some kind of post-depositional warping and faulting had operated on a prism of Triassic rocks whose stratification was essentially parallel throughout at the end of deposition; Barrell (1915) indicated the border fault was active during deposition; W. L. Russell (1922) related the warped structures to movement on the border fault; and Girard Wheeler (1939) carried this suggestion forward to a detailed theory of a genetic connection between the position of the warped structures and changes of attitude on the border fault and showed how this origin required downward movement of the Lowland block along a west-dipping "normal" border fault.

Although I accept the principal conclusions of these workers, I contend that they have all insufficiently considered the consequences of the now well-established interpretation that the border fault was active during Triassic deposition, as well as afterward, an idea suggested by Barrell (1915), and afterward elaborated by W. L. Russell (1922) and C. R. Longwell (1922; 1937). If, as Russell and Wheeler state, the warped structures resulted from post-depositional movements on a "normal" border fault, in which the Central Lowland block moved downward relative to the Eastern Upland block along a westward-dipping fault surface, why did no such warped structures form during the long period of syn-sedimentation faulting, in which the Lowland block also moved downward relative to the Upland block?

The field facts clearly demonstrate that downward movement of the Lowland block took place both during and after deposition of the Triassic strata; but the subject of whether the border fault was "normal" or reversed in each episode is not so clearly established. Longwell (1922), Girard Wheeler (1939), and R. E. Digman (1950) have proved that the facts obtained from Connecticut require the conclusion that steep west dip is the present attitude of the border fault. Downward movement of the Lowland block along such a west-dipping fault is by definition "normal" faulting. By association, the conclusion that earlier downward movement of the Lowland block must have also occurred on a "normal" fault has been assumed, even in the face of a statement by Longwell (1922, p. 231) that the border fault would dip eastward if the beds were rotated back to horizontal and contrary to arguments advanced by Bain (1932) that the border fault in Massachusetts is a reversed fault.

If we accept the interpretation that the border fault acted as a "normal" fault during the post-depositional episode of downward movement of the Lowland block which gave rise to the warped structures, then perhaps we can explain why syn-sedimentation downward movement of this same Lowland block did not cause warped structures by the assumption that the border fault was not behaving as a "normal" fault at this time. If the border fault were a reversed fault during sedimentation, but afterward became a "normal" fault by a change of dip of the fault surface, then downward movement of the Lowland block in each case would be accompanied by different structural conditions.

Closer inspection of this possibility indicates it has many merits. Consider next the problem of the end of sedimentation. Granting the usual assumptions that the border fault was always a "normal" fault and that movement on it was more or less continuous, though intermittent, and that no other particularly important structural episodes were involved in the total deformation, then how can the apparent cessation of Triassic deposition be explained? If the Lowland block moved downward during sedimentation and collected the debris eroded from the uplifted Upland block, why did further movement in this same sense not give rise to more sediment? If we adopt the hypothesis that the border fault was an eastward-dipping reversed fault during sedimentation, then it is necessary to call upon some additional structural event to change the border fault so that it later became a westward-dipping "normal" fault. Regional eastward tilting seems to be a ready-made event. Barrell (in Longwell, 1922) and J. B. Woodworth (1932, p. 158-159) advocated the idea that uparching along the "Taconic geanticline" (Barrell's term) was responsible for the eastward tilting the Triassic strata in the Connecticut Valley belt; might not this same uparching along an axis west of the present Triassic outcrop area have been responsible for changing the dip of the border fault from eastward to westward? And at the same time, might not this regional uplift in the midst of the former depressed area have reversed the drainage and thus have ended the Triassic cycle of sedimentation?

The structural history of Central Connecticut was further complicated by yet a third episode of faulting: that represented by the Lowland fault system along which the warped structures have been offset. Longwell (1922) demonstrated that these Lowland faults (whose existence had been earlier shown by W. M. Davis) form a regional system whose orientation is parallel to that of the border fault and is not due to torsion during warping. The offsets caused by these faults can best be explained as the result of vertical "normal" displacement on a system of faults whose dip is westward. As most of the Lowland faults are "normal" Longwell concluded that the border fault, with which the Lowland faults are parallel, is also a "normal" fault.

The following structural chronology is advocated as one which best fits the facts and interpretations discussed previously:

1) Triassic trough and adjacent upland are initiated by a system of reversed faults. Presumably, this means regional compression. (Though I will not enter into it in detail here, I prefer the "broad terrane" interpretation of the Connecticut Valley and New Jersey Triassic areas. I visualize the original trough as consisting of a large graben. If one applied Bullard's (1936) analysis of the gravity measurements made over the East African Rift Valleys, then he would infer that this Triassic graben originated as a block as thick as the Earth's crust, and that it was forced downward into the subcrust by pressure from the sides. The width of the graben is a function of the thickness of the crust involved. Material at depth must be moved laterally to make room for such a depressed block.)
2) In Connecticut, the Lowland block moved downward and the Upland block to the east moved intermittently upward during the Late Triassic. Material was eroded from the uplifted block and deposited on the downdropped block.
3) At some later time, the formerly downdropped block began to rise, eventually forming the "Taconic geanticline" of Barrell. (Perhaps this episode is the first indication of "relaxation" of crustal compression. The depressed central block, having displaced heavier material below, would tend to rise in order to try to restore isostatic equilibrium.)

This uparching of the formerly dropped block caused the drainage to be reversed (this may have an important bearing on the origin of the drainage pattern of the Atlantic slope), tilted the strata in Connecticut to the east, and rotated the east-dipping border fault to its present westward dip.

4) After arching, the Lowland block again moved downward along the border fault, which now dips westward. In addition, other faults are formed, notably those related to the blocks on which the warped structures are located. The western border fault (Bristol fault) came into being at this time. During this episode of downward movement of the Lowland block, the warped structures formed in positions as diagnosed by Wheeler (1939).

5) Warped structures are displaced by faults of the Lowland fault system, by largely "normal" movement on west-dipping faults, many of which are more or less parallel to the attitude of the border fault.

(Many dikes have been intruded along these Lowland faults, indicating a late episode of magmatic activity unrelated to the three lava flows. That these dikes are not connected to the flows is further suggested by the discovery of the tops of many of them.)

(The last two stages seem to be mechanically related to loss of support from below and general collapse. In the early stages, large blocks moved downward, but afterward considerable fragmentation took place.)

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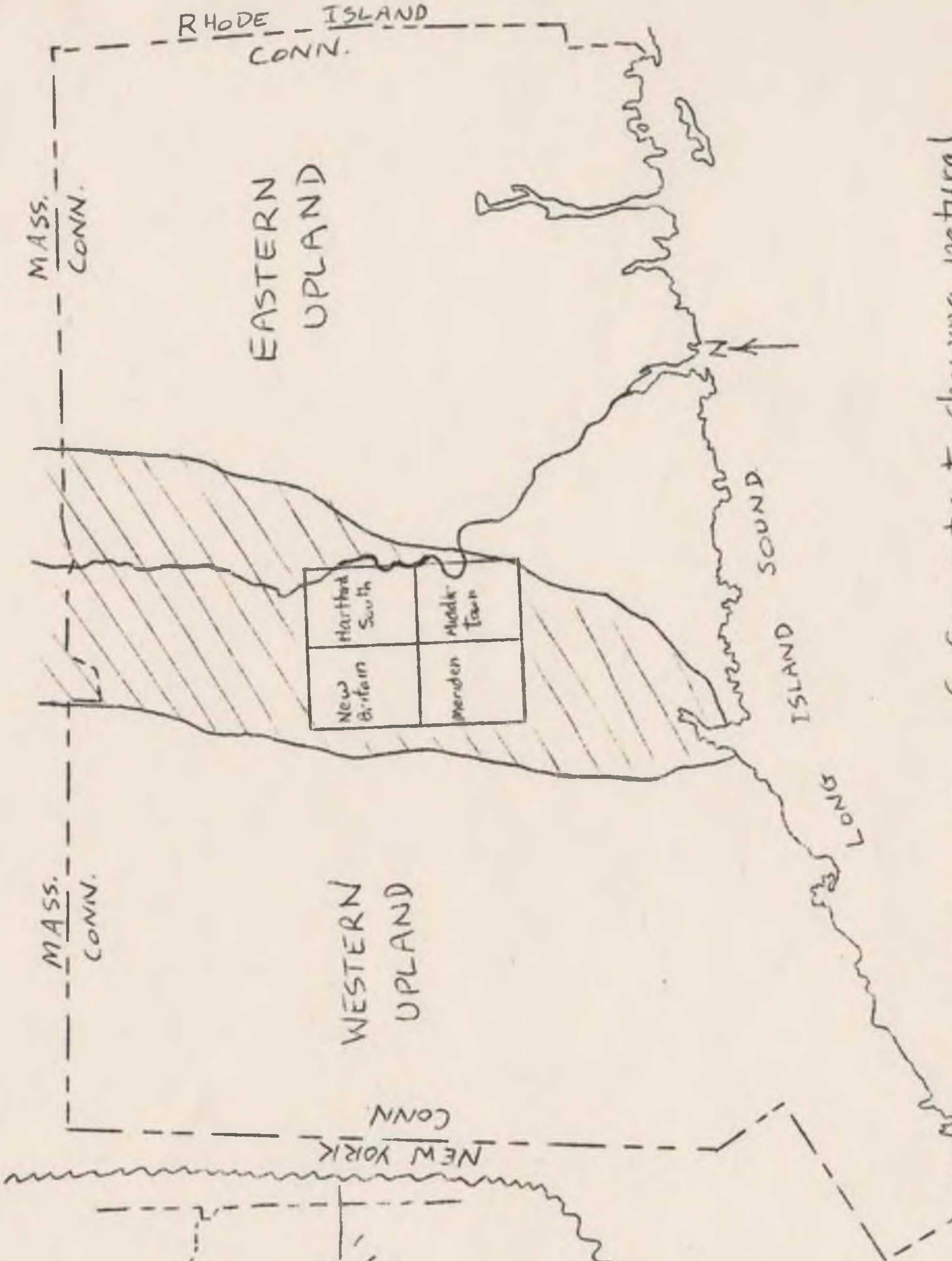

Fig. 1. Index map of Connecticut showing natural regions and location of quadrangles visited by excursion. Central lowland shown by diagonal lines.

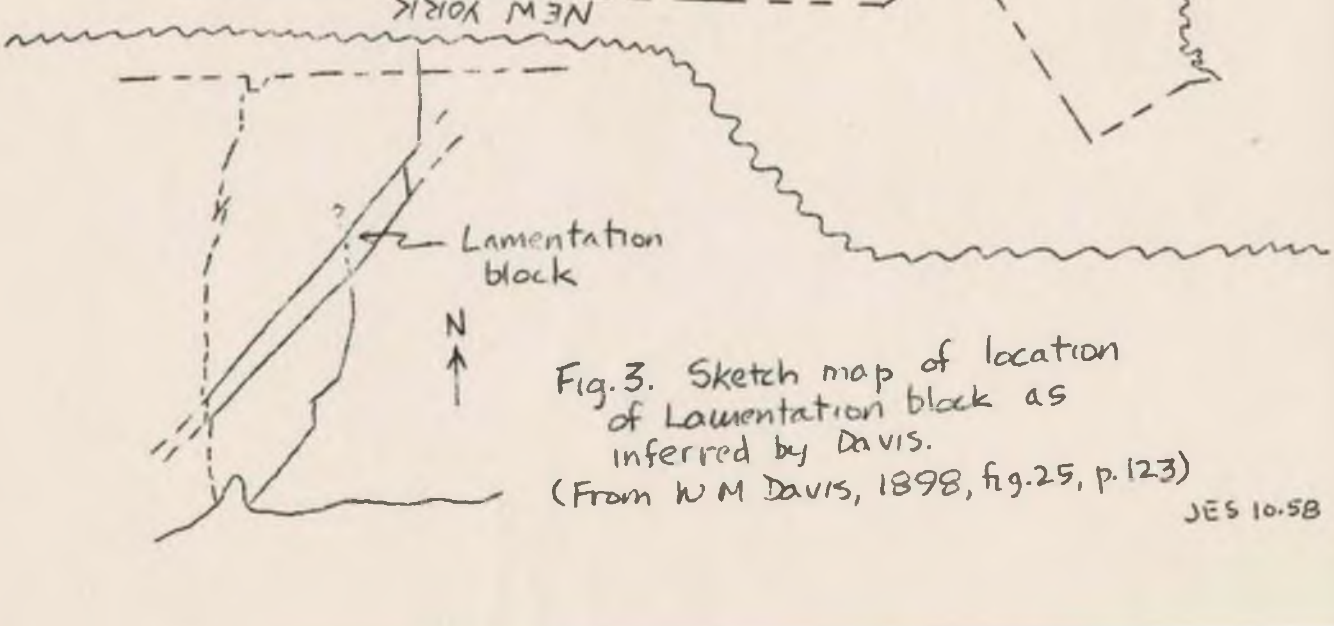

Fig. 3. Sketch map of location of Lamentation block as inferred by Davis. (From W M Davis, 1898, fig. 25, p. 123)

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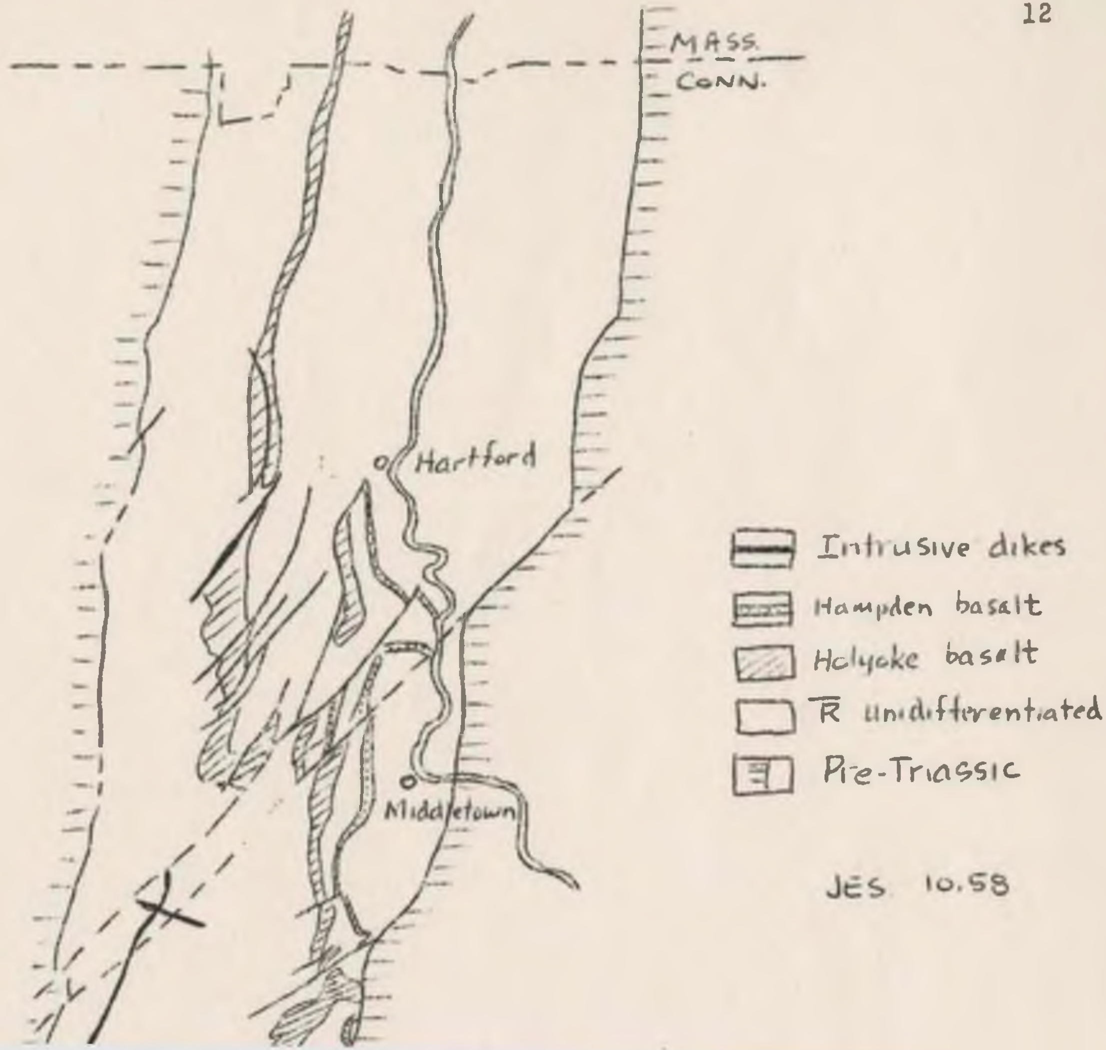

MASS.
CONN.
Hartford
Middletown
Intrusive dikes
Hampden basalt
Holyoke basalt
R undifferentiated
Pre-Triassic
JES 10.58

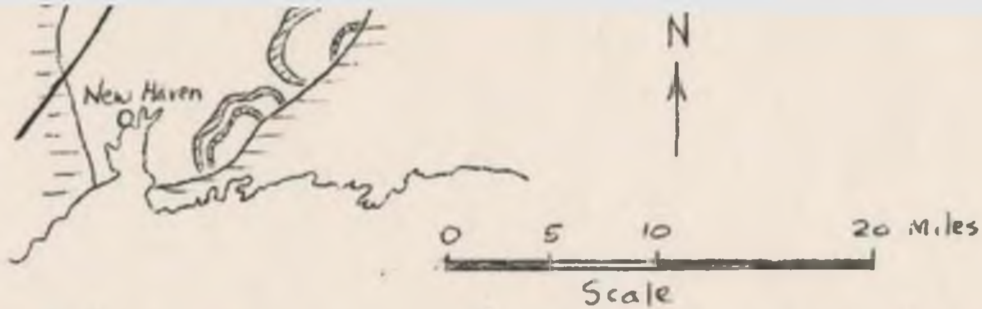
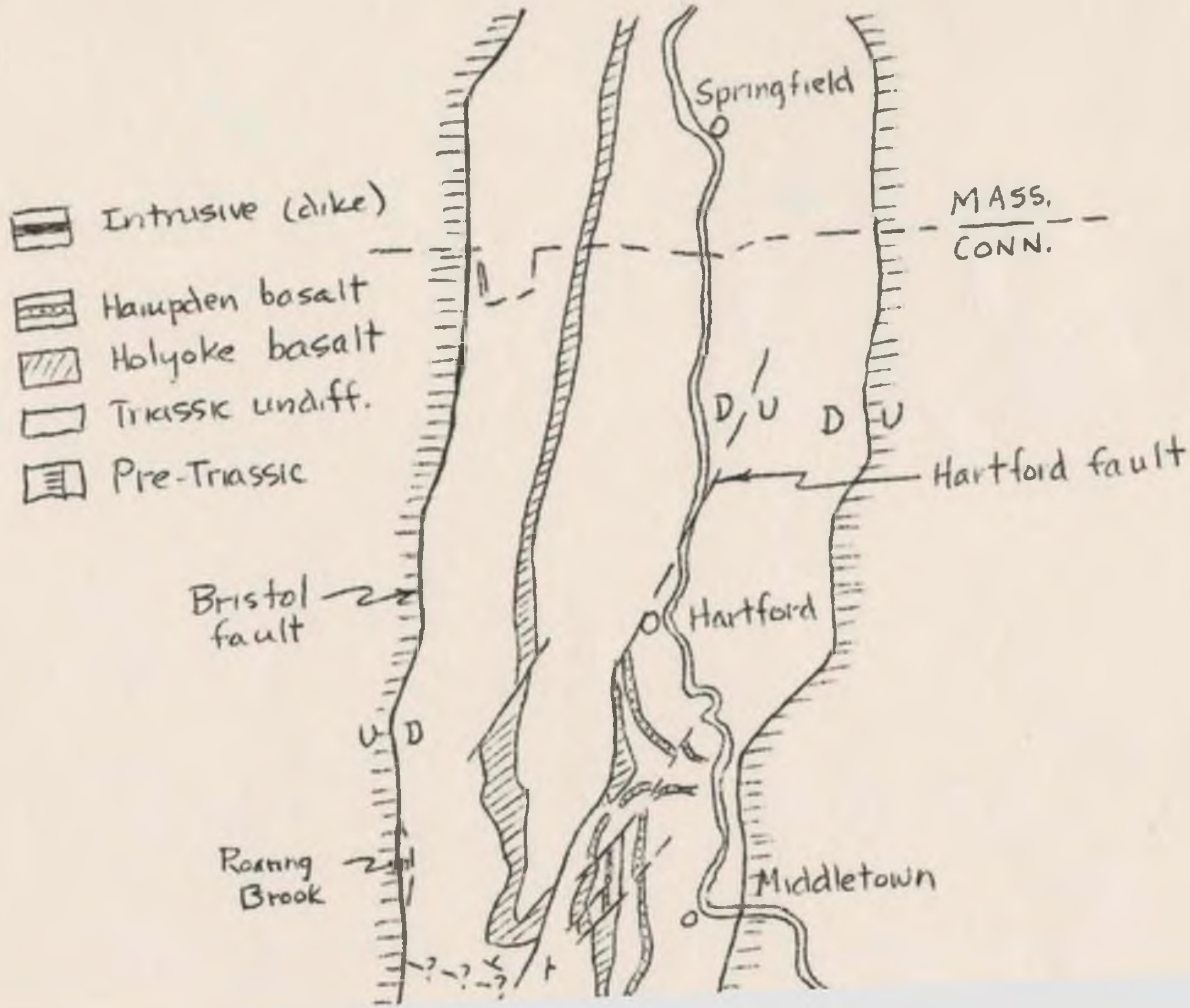


Fig. 4. Partial geologic map of central Connecticut showing W.M. Davis' interpretation of the structural blocks. (Modified from Longwell & Dana, 1933, Pl. I)

Fig. 5. Revised schematic geologic map of parts of central Connecticut Triassic, showing Hartford, Bristol, and Foxon faults and major offsets of warped structures.


Intrusive (dike)
Hampden basalt
Holyoke basalt
Triassic undiff.
Pre-Triassic
Springfield
MASS.
CONN.
D
U
D
U
Hartford fault
Bristol fault
Hartford
U
D
Roaring Brook
Middletown

ROAD LOG

MIDDLETOWN QUADRANGLE

Cumulative milage	Individual distance	
0.0	0.0	Turn Right into Willow Street.
0.1	0.1	Turn Left into Silver Street.
0.2	0.1	(View into Portland brownstone quarries; Brazos quarry)
0.3	0.2	Turn Right into Brownstone Avenue (slow through oil depot)
0.5	0.2	(View across quarry to right)
		Bear Right beyond last building.
0.7	0.2	End of paved road; proceed slowly.
0.8	0.1	Turn Right into old quarry road.
STOP 1.		(Prepare to turn cars around here.) Type locality of Portland formation. Retrace route back to Silver Street;
1.2	0.4	Turn Left into Silver Street
1.5	0.3	STOP STREET. Turn Right onto U.S. 6-A, Conn. 17, cross Connecticut River bridge.
2.4	0.9	Make first Right turn at west end of Bridge (Spring Street)
2.7	0.3	STOP STREET. Turn Left into High Street.
2.9	0.2	STOP for Grand Street. Continue on High St.
3.2	0.3	Traffic light, turn Right on Washington Street.
3.3	0.1	Traffic light, continue westward on U.S. 6-A.
4.4	1.1	(Railway underpass)
4.8	0.4	Blinker light; turn Left on Conn. 157 (West Street)
4.9	0.1	Right turn in Rte. 157.
5.7	0.8	Left turn in Rte 157 (Forest Street)
5.8	0.1	Railroad crossing.
6.2	0.4	Right turn in Rte 157 (Wadsworth Street)
6.3	0.1	(Entrance to Wadsworth Falls State Park)
6.9	0.6	(Railroad grade crossing (Rockfall))
7.2	0.3	Bear Left on Conn. 157.
7.4	0.2	Junction Conn. 157-159; turn Left on Rte 159.
7.6	0.2	Parking space on left side of road.
STOP 2.		Wadsworth Falls (Hampden basalt and base of overlying Portland formation).
		Continue south on Conn. 159
7.7	0.1	Railroad grade crossing; bear right going up hill, but road soon
8.0	0.3	curves to left.
		Turn right on unmarked road by Garden Hill estate. (Cherry Hill on left is a double drumlin.)
8.3	0.3	Cross railroad tracks.
8.5	0.2	STOP STREET; bear Left on Conn. 157.
8.9	0.4	STOP STREET, junction Conn. 217-157. Follow Conn. 157 to Left (Road to Durham).
9.0	0.1	Cross Railroad tracks
9.4	0.4	Turn Right into Conn. 147 (road to Meriden).
9.5	0.1	Railroad underpass and Ellen Doyle Brook; bear Right on Conn. 147 at underpass.
9.6-9.7	0.1-0.2	[Exposures of Hampden basalt (near base) on left side of road; top beds of underlying East Berlin formation exposed in Creek bed on right by curve sign. Road is on contact here. Beds in creek strike N 15°E, dip 15°E.]
9.9	0.2	Road from Durham enters on left; bear Right on Conn. 147.
10.0	0.1	Cross roads at Baileyville. Turn left on un-numbered road (Powder Hill Road; follow signs to Happy Acres and Sauna). Keep to left going uphill (avoid road marked Dead-End).

Cumulative milage	Individual distance	
10.1	0.1	Pass Happy Acres (on R.) [Ridge on right, to west, is Beseck Mountain, underlain by Holyoke basalt]
10.5	0.4	Pass Sauna (on R.); Long Hill Road enters on left; continue south on Powder Hill Road.
10.7	0.2	Dinosaur footprint locality.
STOP 3.		(Parking a problem here, we may have to visit the outcrops in shifts and ask those who have seen them to move cars on ahead.) About middle of East Berlin formation.
		Continue south on Powder Hill Road. (Powder Hill is a drumlin. Large orchard here illustrates common southern Connecticut practice of using drumlins for orchards.)
11.3	0.6	(View ahead, to south, of Reed Gap quarry in Holyoke basalt. At top of hill notice Beseck Mountain, underlain by Holyoke basalt, on the right, and Eastern uplands, underlain by igneous and metamorphic rocks, in distance to left.)
		DURHAM QUADRANGLE
11.5	0.2	Turn Left on unmarked road. Proceed slowly past orchard buildings. (View of Eastern Uplands in distance to east)
12.1	0.6	Turn Left on road toward Lyman Farm.
		MIDDLETOWN QUADRANGLE
12.6	0.5	"T" intersection, turn Left.
13.1	0.5	Lyman Gunsight Factory.
13.3	0.2	STOP. Junction Conn. 147. Baileyville Bear Left on Rte 147.
13.4	0.1	Baileyville cross-roads. Continue straight ahead on 147, which then bears left and soon curves to right.
14.0	0.6	(Beseck Lake on left; outcrops on right side of road are near base of East Berlin formation.)
14.9	0.9	Road curves to left.
15.0	0.1	(Outcrop near top of Holyoke basalt on left side of road.)
15.2	0.2	TRAFFIC light, Junction Conn. 147 and U. S.6-A. Turn Left on 6-A. (Outcrops of Holyoke basalt on left and along Rte 6-A for next mile)
15.8	0.6	(Cuts in Holyoke basalt on both sides of highway)
16.1	0.3	(Black Pond on left; left turn to newly discovered dinosaur bone locality.)
16.2	0.1	(Enter Meriden) -
		MERIDEN QUADRANGLE
16.4	0.2	(Outcrops of Talcott basalt, showing pillows and pipe-stem amygdules.)
16.6	0.2	BLINKER Light; turn Right (Preston Avenue).
16.8	0.2	(Outcrops of Talcott basalt in driveways on right) (Peaks in distance to left are part of Hanging Hills)
17.0	0.2	(View of Chauncey Peak ahead) -
17.6	0.6	(View of Beseck Mtn. on right, Chauncey Peak ahead, and Hanging Hills in distance to left; all are underlain by Holyoke basalt.)

		(Preston Avenue is on Talcott basalt, but no outcrops are present here.)
17.8	0.2	Turn Left on unmarked road (Baldwin Avenue). (Outcrops of Talcott basalt on right.)
18.1	0.3	(Outcrops of pebbly New Haven arkose in bank on right side of road, just beyond Preston Drive.)
18.6	0.5	STOP Street. Turn Right on Bee Street.
18.8	0.2	Railroad crossing.
19.0	0.2	STOP Street. Bear right and continue straight ahead (following signs to York Hill Trap Rock Company); road soon curves to right.
19.2	0.2	(Outcrops of Talcott basalt in creek bank to left)
19.4	0.2	(Entrance to International Silver Company Bradley Hubbard Reservoir on left)
19.9	0.5	(Large quarry in Holyoke basalt of Chauncey Peak block on left)
21.1	0.2	Enter Middletown. (Exposures of stratified drift in 280-ft terrace on right by Benny's Miniature Golf Course) -
21.2	0.1	(Basalt outcrop on left of road is near the top of the Holyoke flow of the Chauncey Peak block.)
21.3	0.1	MIDDLETOWN QUADRANGLE
43.3 22.0	0.7	Highland. Turn left on Country Club Road. (From here northward for next 2.7 miles the road follows a strike valley in the East Berlin formation. Several prominent drumlins are found in this valley, the largest being Snow Hill. Note the orchard on it.)
24.4	2.4	(View of Hanging Hills in distance to left.)
24.7	0.3	Intersection Savage Hill Rd and Spruce Brook Rd. Turn Left on Spruce Brook Rd.
25.0	0.3	Hanson dairy farm (turn into yard beyond new barns)
46.8 STOP 4.		Contact of top of Holyoke basalt and base of East Berlin fm. in bend of Spruce Brook. Walk down farm lane, pass gate, and follow to end of cleared cowpath which leads west along fence line. Cross fence at end of path and descend to stream level.
25.3	0.3	Turn around and proceed eastward on Spruce Brook Road, retracing route to jct. of Savage Hill Rd. Turn Left on Savage Hill Rd.
25.6	0.3	(Savage Hill, a drumlin)
25.9	0.3	STOP Street. Turn Left onto Route 72 (Mill Street).
26.6	0.7	Roadcuts in Hampden basalt.
26.7	0.1	Roadcuts in East Berlin fm.
48.3 STOP 5.	Pull over to the right as far as possible for parking.	East Berlin fm. and Hampden basalt. Be careful of traffic. (This will be a long stop and is planned to coincide with lunch. The diners on Highway 15 provide rest rooms, coffee, etc.)
		HARTFORD SOUTH QUADRANGLE
26.9	0.2	Entrance to Wilbur Cross Highway (Conn. 15). Turn Right (toward Hartford).
27.0	0.1	Enter northbound lanes of Wilbur Cross Highway. Proceed northward.
28.1	1.1	Jct. Deming Rd (Conn. 160); turn Right, following signs to Rocky Hill.

28.9	0.8	Wethersfield Rd enters from Right. Route 160 curves gently to Left (Road now follows a strike valley in the East Berlin formation on the Cedar Mountain "anticline." Hampden basalt underlies wooded ridge south of highway; Holyoke basalt forms Vexation Hill to the north).
29.7-29.9	0.8-1.0	(Holyoke basalt in hills to left).
30.1	0.2	(Outcrops of East Berlin fm in driveway on Right side of road)
30.7	0.6	(More outcrops of East Berlin fm)
30.8	0.1	(Hayes Rd enters from left. Outcrops of East Berlin fm present in cuts 0.1 mi N. on Hayes Rd) -
31.5	0.7	STOP Street. Turn Right onto Conn. 3 and 160 (Cromwell Ave.) following Rocky Hill signs.
31.7	0.2	Bear Right on Conn. 3
32.3	0.6	Turn Left on West Street, toward Conn. State Veterans' Hospital.
32.8	0.5	(Powerline crosses overhead)
33.1	0.3	(Ditch by new house on Right exposes contact between top of East Berlin fm and base of Hampden basalt, which has been offset to south)
33.2	0.1	(Gilbert Ave. enters from left; continue on West St.).
34.4	1.2	Jct. Conn. 9. (Silas Dean Hwy) - Turn Left toward Rocky Hill.
35.1	0.7	Multiple intersection; bear Right on Conn. 160, but then immediately turn a 45° right (not a 90° right, as does Conn. 160) following street which passes to the right of a white frame church.
35.3	0.2	Crossroads. Turn Left on Main Street. (Ridge just ahead is underlain by Hampden basalt on the northeast limb of the Cedar Mtn "anticline." An abandoned quarry is present on the NE side of the ridge.)
36.2	0.9	(outcrops of Hampden basalt on Right) -
36.5	0.3	(Railway grade crossing)
36.9	0.4	Jct. Middletown Ave. and Mill St.; turn Left on Mill St.
37.1	0.2	Intersection Mill St., Conn. 9. Continue west on Mill St.
37.3	0.2	Jct. Conn. 3. Mill Street ends. Turn Right on Conn. 3 (Maple St.)
37.7	0.4	Turn Left on Prospect St.
38.8	1.1	Intersection Prospect St.-Ridge Rd. Turn Right on Ridge Rd.
39.0	0.2	Outcrops of Hampden basalt in rock gardens on Left.
39.5	0.5	STOP Street. Conn. 175 (Wells Rd). Turn Left on Conn. 175. (Ridge Road continues north along outcrop belt of Hampden basalt, as part of Springfield "half basin."
40.5	1.0	Pass under Wilbur Cross Highway on Conn. 175; proceed west toward New Britain
40.7-41.2	0.2-0.7	Outcrops of Holyoke basalt of Cedar Mtn.
41.7	0.5	Newington Main Street intersection and traffic light. Turn Right on Main Street.
42.7	1.0	Turn Right on Conn. 176 (Hartford Ave.)
43.4	0.7	Edw. Balf Co. quarry in Holyoke basalt of Cedar Mtn on right.
44.1	0.7	(Holyoke basalt on Right)
44.6	0.5	Traffic light at Jct. U.S. 6 (New Britain Ave.). Turn Right (Holyoke basalt on Right).
44.8	0.2	Move into Center lane for Left turn at next traffic light. Turn Left on Truck Route U.S. 6, following signs to Trinity College (New Britain Ave.).
45.5	0.7	Turn Left at Zion Street (Traffic light here)
45.8	0.3	Traffic Light. Bear Right on College Terrace. (Contact of East Berlin fms and Hampden basalt is exposed in Rock Ridge Park on Right).
45.9	0.1	Right turn on Summit Street
46.3	0.4	Traffic light at New Britain Ave. Continue straight across intersection.

46.4	0.1	STOP Street. Bear Left on Fairfield Ave.
46.6	0.2	(Glacially polished surface and grooves on Hampden basalt on Right).
47.4	0.8	STOP at blinker light. Intersection of Maple Ave. Bear Right following U.S. 5-A.
48.5	1.1	(Overpass for southbound lane of Wilbur Cross Highway.)
49.5	1.0	(Jct. Wilbur Cross Hwy and Conn. 175).
50.2	0.7	(Outcrop of Holyoke basalt on Right).
52.6	2.4	(Profile view ahead of Lamentation Mtn. Bench on west side is underlain by Talcott basalt, Main ridge by Holyoke basalt.
54.9	2.3	(Jct. Wilbur Cross Hwy and Conn. 72)
		MIDDLETOWN QUADRANGLE
		After 1.7 mi. enter MERIDEN QUADRANGLE
58.3	3.4	Turn off Wilbur Cross Hwy at U.S. 5-A, following Meriden sign (Broad Street)
59.4	1.1	(Outcrop of New Haven arkose on left)
59.6	0.2	Blinker light.
60.4	0.8	Railroad underpass. New Haven arkose outcrops beyond on Right.
60.6	0.2	Bear Right onto New Colony St.
60.6	0.3	(Railway grade crossing)
		After crossing, turn Right onto Kensington Avenue.
60.9	0.3	(R.R. overpass; New Haven arkose exposed at street corner on right).
61.0	0.1	(More New Haven arkose on Right). Kensington Ave. curves Right, then Left.
61.2	0.2	Turn Right into Bailey Ave.
61.4	0.2	Turn Left into Gay St. Proceed to end of street.
61.5	0.1	Sangavani Sand and Gravel Pit, near cor. Gay and Summary Sts.

STOP 6. **Exposure of Hartford fault.**
New Haven arkose faulted against Holyoke basalt of Cathole Mtn block.
Exposure also reveals typical stratified drift.

		Turn Right into Summary St.
61.6	0.1	"T" intersection with Kensington Ave.; turn Right.
61.9	0.3	(Outcrop of Shuttle Meadow fm on Cathole block on left)
62.1	0.2	"T" intersection with Conn. 71 (Chamberlain Hwy). Turn Right.
62.2-62.7	0.1-0.5	Outcrops of Holyoke basalt. (Berlin Town line, New Haven-Hartford County line at 0.5)
63.3	0.6	Turn Left on Butler St.
65.5	0.2	Turn sharp Left into Park Drive.
66.0	0.5	(Road enters on right)
66.9	0.9	Sharp Right turn. Bear around to Right and cross small bridge at head of Merimere reservoir.
67.4	0.5	Sharp Left turn in road.
		(From here to top, the road nearly follows a dip slope of Holyoke basalt of the Hanging Hills.)
68.3	0.9	"Y" intersection in road, bear Left for East Peak.
68.7	0.4	STOP 7.
		Stone tower at East Peak.
		If clear, the view from here is very instructive. To the east are Lamentation Mtn, Chauncey Peak, Higby and Besock Mtns and Reed Gap underlain by Holyoke basalt of the Middletown "half basin"; to the south are Mt. Carmel and East Rock (intrusive masses); to the southwest is West Rock ridge (tilted sill of dolerite), and to the west, the metamorphic rocks of the Western Uplands.
		Retrace route to head of Merimere reservoir.
70.5	1.8	Turn right on Park Drive, following along east side of Reservoir.

70.9	0.4	(Outcrops of Holyoke basalt on left)
71.2	0.3	(Outcrops of Shuttle Meadow fm on left opposite island in Reservoir).
71.4-71.5	0.2-0.3	(Outcrops of Talcott basalt on left)
71.9	0.4	Reservoir Ave. enters on left; make Left turn into Reservoir Ave.
72.5	0.6	(Outcrops of New Haven arkose just west of intersection of Fowler Ave. and Reservoir Ave.)
72.6	0.1	Corner Fowler Ave. and Reservoir Ave.; turn Right on Fowler Ave.
72.8	0.2	"T" intersection; Fowler Ave. ends against U.S. 6-A (Main St.) Cross 6-A to study outcrop of sandstone by Dari-Queen.
94.5		STOP 8. New Haven arkose. Strike and dip indicates this outcrop is on the Middletown block and that the Hartford fault passes northwest of this hill. We will proceed east on 6-A from here.
73.0	0.2	(Traffic light; Conn. 71 enters on left)
73.2	0.2	Traffic light. Turn Right on divided parkway, Conn. 71 (Bradley Ave.)
73.5	0.3	STOP Street. Continue on Bradley Ave.
74.0	0.5	(Large street enters on left; continue straight on Bradley Ave.)
75.0	1.0	Intersection Conn. 71-70; Turn Right on Conn. 70 (New Haven Ave.) Cross Quinnipiac River. Hanover Pond on Right.
75.5	0.5	Traffic light; turn Right with caution on continuous green arrow when main signal is red.
75.7	0.2	Hanover Pond outcrops of New Haven arkose on left around curve in road.
75.9	0.2	Turn Right, across bridge and park in open space beyond.
97.6		STOP 9. New Haven arkose of Hanging Hills block (NW strike, NE dip). Note coarse channel deposits and finer grained floodplain sediments. Many small faults are present here and on the south side of the Quinnipiac River, with abundant slickensides.

END OF TRIP. Best way back to Middletown: Retrace route on Conn. 70 past Hanover Pond.

76.3	0.4	Traffic light. Turn left on Conn. 70.
76.8	0.5	Jct. Conn. 71-70; turn Right on Conn. 71.
77.4	0.6	Outcrop of basalt dike on left, opposite cemetery
77.6	0.2	Jct. Conn. 71, U.S. 5-A. "T" intersection. Turn Right on U.S. 5-A.
78.6	1.0	Intersection U.S.5-A and South Broad St. U.S. 5-A turns Left and passes under narrow R.R. overpass. LEAVE MERIDEN QUADRANGLE.
78.8	0.2	Blinker light at Jct. U.S. 5-A and U.S. 5. Enter U.S. 5 (going South).
79.2	0.4	Jct. U.S. 5 and Wilbur Cross Parkway. Pass under Parkway and take second left (Hartford signs).
81.4	2.2	Exit from Parkway to U.S. 6-A. Follow Middletown signs.
87.7	6.3	R.R. overpass at edge of Middletown. Continue on U.S. 6-A.
88.2	0.5	Wesleyan campus on right.

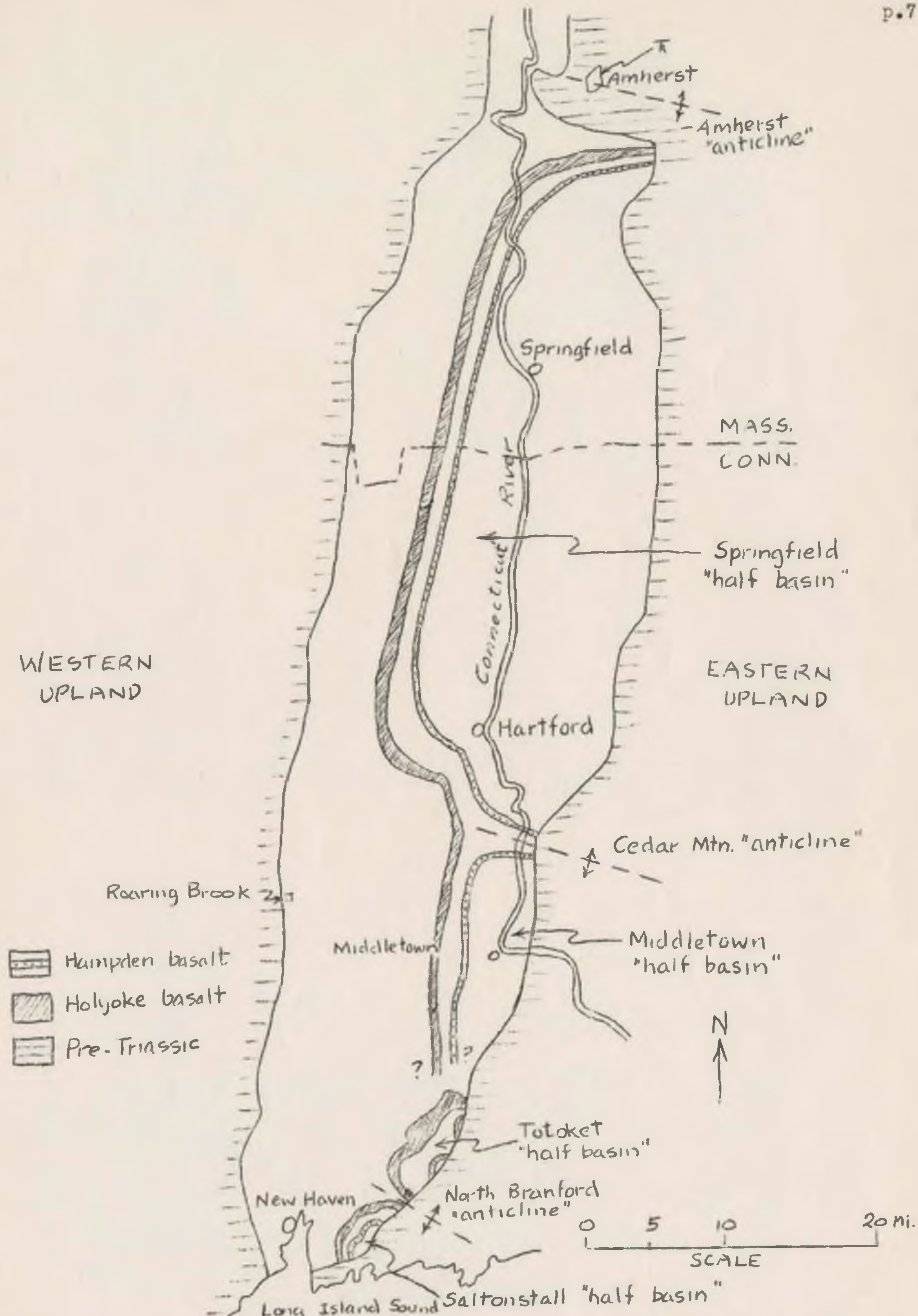


Fig. 2 Partial, schematic geologic map showing inferred position of warped structures in Connecticut valley Triassic prior to displacement on Lowland fault system. (Base from Longwell & Dana, 1933). JES 10.58